Assessing Multivariate Constraints to Evolution across Ten Long-Term Avian Studies

Celine Teplitsky[1]*, Maja Tarka[2], Anders P. Møller[3], Shinichi Nakagawa[4], Javier Balbontín[5], Terry A. Burke[6], Claire Doutrelant[7], Arnaud Gregoire[7], Bengt Hansson[2], Dennis Hasselquist[2], Lars Gustafsson[8], Florentino de Lope[9], Alfonso Marzal[9], James A. Mills[10], Nathaniel T. Wheelwright[11], John W. Yarrall[12], Anne Charmantier[7]

1 Département Ecologie et Gestion de la Biodiversité UMR 7204 CNRS/MNHN/UPMC, Muséum National d'Histoire Naturelle, Paris, France, 2 Department of Biology, Lund University, Ecology Building, Lund, Sweden, 3 Laboratoire d'Ecologie, Systématique et Evolution, CNRS UMR 8079, Université Paris-Sud, Orsay, France, 4 Department of Zoology, University of Otago, Dunedin, New Zealand, 5 Department of Zoology, Biology Building, University of Seville, Seville, Spain, 6 Department of Animal and Plant Sciences, University of Sheffield, Sheffield, United Kingdom, 7 Centre d'Ecologie Fonctionnelle et Evolutive UMR 5175 CNRS, Montpellier, France, 8 Department of Animal Ecology, Evolutionary Biology Center, Uppsala University, Uppsala, Sweden, 9 Departamento de Zoología, Universidad de Extremadura, Badajoz, Spain, 10 Corning, New York, United States of America, 11 Department of Biology, Bowdoin College, Brunswick, Maine, United States of America, 12 Lincoln, Christchurch, New Zealand

Abstract

Background: In a rapidly changing world, it is of fundamental importance to understand processes constraining or facilitating adaptation through microevolution. As different traits of an organism covary, genetic correlations are expected to affect evolutionary trajectories. However, only limited empirical data are available.

Methodology/Principal Findings: We investigate the extent to which multivariate constraints affect the rate of adaptation, focusing on four morphological traits often shown to harbour large amounts of genetic variance and considered to be subject to limited evolutionary constraints. Our data set includes unique long-term data for seven bird species and a total of 10 populations. We estimate population-specific matrices of genetic correlations and multivariate selection coefficients to predict evolutionary responses to selection. Using Bayesian methods that facilitate the propagation of errors in estimates, we compare (1) the rate of adaptation based on predicted response to selection when including genetic correlations with predictions from models where these genetic correlations were set to zero and (2) the multivariate evolvability in the direction of current selection to the average evolvability in random directions of the phenotypic space. We show that genetic correlations on average decrease the predicted rate of adaptation by 28%. Multivariate evolvability in the direction of current selection was systematically lower than average evolvability in random directions of space. These significant reductions in the rate of adaptation and reduced evolvability were due to a general nonalignment of selection and genetic variance, notably orthogonality of directional selection with the size axis along which most (60%) of the genetic variance is found.

Conclusions: These results suggest that genetic correlations can impose significant constraints on the evolution of avian morphology in wild populations. This could have important impacts on evolutionary dynamics and hence population persistence in the face of rapid environmental change.

Estimation of the additive genetic (co)variance matrix

G

+

G

$$y = \mu + \quad + Z \quad + Z \quad + Z \quad + \qquad (1)$$

$\boldsymbol{\mu}$

$a \sim N(0, G \otimes A)$ **G**

A

Estimating selection

$\boldsymbol{\beta}$

γ

G

[redacted]able 4. Estimates of mean standardize[redacted] traits [redacted] estimated $V_A \times 10$[redacted] [redacted]ee Blue tit populations with their 95% confidence [redacted]nterval.

	Blue tit - Muro			Blue tit - Piri[redacted]			Blue tit - Rouvière		
	posterior mode	Lowe[redacted]95%CI	[redacted]	posterior mo[redacted]	[redacted]	Upper 95%CI	posterior mode	Lower 95%CI	Upper 95%CI
Wing	0.018	0.013	[redacted]	0.013	[redacted]	0.018	0.02	0.015	0.024
Tarsus	0.041	0.027	[redacted]	0.043	[redacted]	0.058	0.043	0.035	0.054
Mass	0.075	0.042	[redacted]	0.079	[redacted]	0.11	0.103	0.077	0.131
Bill	0.045	0.028	[redacted]	0.028	[redacted]	0.041	0.05	0.038	0.065
Wing:Tarsus	0.01	0.003	[redacted]	0.012	[redacted]	0.017	0.007	0.002	0.011
Wing:Mass	0.012	0.002	[redacted]	0.012	[redacted]	0.022	0.017	0.009	0.025
Wing:Bill	0.008	−0.00[redacted]	[redacted]	0.007	[redacted]	0.011	0.006	0	0.011
Tarsus:Mass	0.021	0.006	[redacted]	0.029	[redacted]	0.046	[redacted]	0.012	0.035
Tarsus:Bill	0.019	0.006	[redacted]	0.013	[redacted]	0.022	0.01	0.002	0.018
Mass:Bill	0.032	0.008	[redacted]	0.017	[redacted]	0.03	[redacted]	0.015	0.042

I_A-evolvabilities were higher for mass than for othe[redacted] characte[redacted] c scale of this measu[redacted] aracters were measured on a linear scale [40].

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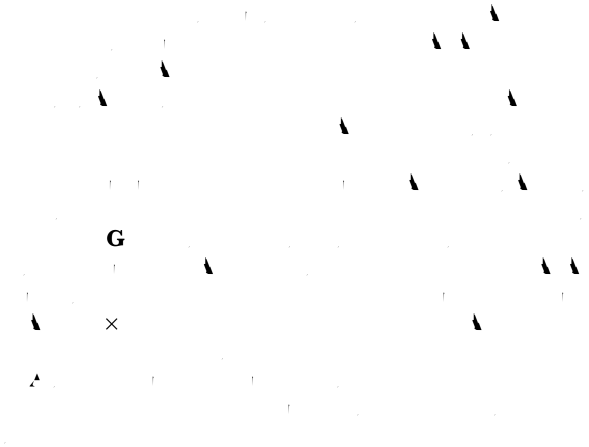
$$\beta = \frac{\boldsymbol{\beta}^T \mathbf{G} \boldsymbol{\beta}}{\|\boldsymbol{\beta}\|^2} \tag{4}$$

Table 7. Estimates of directional and non-linear selection gradients for the Red-billed gull, Great reed warbler, and the two Barn swallow population [redacted] intervals.

	Red-billed gull			Great reed warbler			Barn swallow - Badajoz			Barn swallow [redacted]		
	posterior mode	Low 95%CI	Up 95%CI	posterior mode	Low 95%CI	Up 95%CI	posterior mode	Low 95%CI	Up 95%CI	posterior mo[redacted]	[redacted]	[redacted]
$\|\| \beta \|\|$	4.22	1.94	7.24	5.23	2.53	8.17	0.54	0.22	1.48	1.06	[redacted]	[redacted]
Wing	1.14	−2.75	5.9	−0.09	−3.79	4.12	0.33	−0.72	1.5	−0.54	[redacted]	[redacted]
Tarsus	1.86	−1.12	4.39	4.04	1.45	7.69	0.12	−0.48	0.65	0.7	[redacted]	[redacted]
Mass	−1.15	−2.39	0.32	−1.78	−3.02	−0.51	0.08	−0.27	0.44	−0.17	[redacted]	[redacted]
Bill	1.86	−1.83	5.35	0.58	−1.48	1.96	0.15	−0.25	0.59	0.32	[redacted]	[redacted]
$Wing^2$	139.96	−27.15	243.35	15.61	−107.1	233.37	−13.47	−35.27	7.07	41.28	[redacted]	[redacted]
$Tarsus^2$	29.1	−33.29	88.21	24.88	−61.64	128.76	2.78	−5.35	9.58	1	[redacted]	[redacted]
$Mass^2$	9.26	[illegible]	[illegible]					−35(35)-7			[redacted]	[redacted]



Natural selection on morphology

β

β

Discussion